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# DEVELOPMENT OF ENERGY DISSIPATING PLASTIC HONEYCOMB

## QUARTERLY PROGRESS REPORT NO. 4

APRIL 1, THROUGH JULY 31, 1966

CONTRACT NO. 951172

CALIFORNIA INSTITUTE OF TECHNOLOGY
(JET PROPULSION LABORATORY)
4800 OAK GROVE DRIVE
PASADENA, CALIFORNIA

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# SECTION 1
# SUMMARY

Static crushing tests were performed on 14 pcf, thinned dip, improved bond specimens after the specimens had been exposed to the sterilization cycle specified in the Program Plan. Unsterilized material, cut from the same log of honeycomb, was tested and used for comparison of energy absorption values. No significant change in material properties of the sterilized specimens was observed.

Two high-velocity impact tests were performed at 500 fps on 14 pcf, thinned dip, improved bond specimens. Visual observation of the specimens after impact indicated that the material crushed in an orderly manner, but unfortunately, no quantitative data were obtained due to failure of the instrumentation used in the tests. Preparations are being made to rerun these tests.

Tooling used in fabrication of the flat dovetail specimens was completely reworked to include all metal parts which replaced wooden parts in the original tooling. Using the new tooling, the first successful specimen of the dovetail design was fabricated. Configuration detail obtained was excellent and the strength of the bond lines is equal to or greater than that obtained on the standard production honeycomb. Due to a delay in shipment, the first specimen did not arrive at the General Electric Company in time to be tested during this reporting period. The balance of the specimens are scheduled to be completed by 6 August, 1966.

Knowledge gained during the fabrication of the flat dovetail specimens has shown that the size of dovetail design specimens that can be manufactured, is limited, to a great extent, by the short time cycle available for assembling the piece. To keep assembly time within allowable limits will require the use of more elaborate tooling than that used in fabricating the four-inch cube size specimens.

Because this tooling requirement is considerably more complex than originally anticipated, a problem is foreseen in fabricating specimens for the doubly curved specimen tests within the originally projected scope and time schedule. It is recommended, therefore, that a meeting be held with the customer to discuss this problem prior to initiation of tooling procurement and fabrication of the doubly curved specimens.

## SECTION 2

## FABRICATION OF DOVETAIL SPECIMENS

### 2.1 DISCUSSION

It was desired, as a part of this program, to fabricate a new cell configuration of honeycomb designated the dovetail type. There are two standard methods of producing honeycomb: (1) the expansion method, and (2), the corrugated method. Because the shape of dovetail core does not lend itself to fabrication by the expansion process, the corrugated process was selected. The problems incurred in using the corrugated process resulted from the attempt to use resin materials identical to those used in the expansion process. The core material currently fabricated by the corrugated process is made from a polyester resin; it was desired to fabricate the new dovetail material from a nylon-phenolic resin used in the expansion process.

Conventional glass reinforced phenolic honeycomb is made by impregnating glass cloth with a nylon modified phenolic resin to make a soft pre-preg sheet which is painted with lines of adhesive used to form the honeycomb node bonds. The distance between adhesive lines determines the cell size of the honeycomb. The adhesive painted sheet is cut into appropriate lengths, stacked, and allowed to bond at room temperature under a small pressure. This process forms a block that is bonded by discrete stripes of adhesive, with alternate sheets having stripes midway between each other. To make a honeycomb piece, the block is mechanically expanded while being heated. After expansion, the honeycomb is held in position and cured in order to stabilize the cell structure. Subsequently, the honeycomb log is dipped in resin and cured in a number of repeated cycles until the desired density is achieved.

This process is greatly dependent on the way in which the materials interact with each other in order to make a good structure. The resin used to impregnate the cloth must be soft enough to be flexibilized by the application of moderate amounts of heat, yet it must not be tacky, and it must be capable of being post cured to a rigid entity. It is because of these reasons that a nylon modified resin is used for the phenolic-glass honeycomb. It is apparent, then, that the limitations of the process place severe restrictions on the type of impregnating resin that can be used. This restriction must be taken into consideration in devising fabricating techniques for experimental honeycombs using high performance polyester and epoxy resins. The node bond adhesive has a working life of about two hours, and adheres well to the relatively soft impregnated sheet used in the expansion process.

The cell configurations that can be made by the expansion process are governed by the extent to which the structure is deformed--whether it is underexpanded to give a boat shape, expanded to a hexagonal shape, or overexpanded to form a lozenge shaped cell. Recurved configurations, or true rectangular cell shapes, cannot be made by the expansion process, and to produce the so called dovetail, T shape, or rectangular cell configurations, it is necessary to use preformed sheets that are then glued together to make the desired structure. If it is desired to use the same materials as in the expansion process, some difficulties must first be overcome, because the preforming process makes a sheet that must be partially cured to become stable, and the bond line adhesive does not adhere readily to an impregnated sheet in a partially cured condition.

A number of experiments were then performed to see if the adhesive could be made to stick to the preformed sheets. Eight specimens were made, as follows:

a. Node bond adhesion at RT, 16 hours,contact pressure.

b. Node bond adhesion at RT, 16 hours, 5 PSI pressure.

c. Node bond adhesion at 250$^{\circ}$F, one hour, contact pressure.

d. Node bond adhesion at 250$^{\circ}$F, two hours, contact pressure.

e. Node bond adhesion at 300$^{\circ}$F, 30 minutes, contact pressure.

f. Node bond adhesion at 300$^{\circ}$F, one hour, contact pressure.

g. Node bond adhesion at 250$^{\circ}$F, two hours, 5 PSI pressure.

h. Node bond adhesion at 300$^{\circ}$F, one hour, 5 PSI pressure.

These experiments showed that at room temperature, for sixteen hours, neither specimen adhered. Adhesion was so poor that the adhesive film distorted and peeled off the cloth. At $250^{o}$F, adhesion was poor at the end of one hour, and good at the end of two hours, at both contact and 5 PSI; at $300^{o}$F, adhesion was good at the end of 30 minutes, and excellent at the end of 60 minutes, at both contact and 5 PSI. Further experiments with the adhesive showed that it was still effective 90 minutes after being mixed, developing a good bond when cured at $300^{o}$F.

## 2.2 DOVETAIL SPECIMENS EXPANDED 50 PERCENT

The initial method used to fabricate a dovetail specimen follows.

a. Sheets of glass cloth impregnated with phenolic resin are placed, one at a time, in a die having the configuration diagrammed in Figure 2-1.


Figure 2-1. Forming Impregnated Sheets

b. The loaded die is placed in an oven for a short period of time to partially cure the resin, forming a stable structure.

c. The formed sheet is unloaded from the die, and the operations are repeated until a sufficient number of sheets are formed to make a honeycomb block about 4 inches thick.

d. When a sufficient quantity of sheets have been formed, they are stacked with adhesive at the nodes to form a block.

Great difficulty was experienced in making these blocks because pressure could not be put on the nodes without deforming the walls of the structure to the point where collapse occurred.

The process was then modified to include a base fixture and forming tools that would permit pressure to be exerted on the built-up specimen and thereby ensure good bond contact at all areas. The tooling was fabricated from wood which happened to be a bad choice due to the lack of dimensional stability. This became apparent when the first specimen was assembled. Variations in forming tool dimensions caused the specimen to become irregular when pressure was exerted during the curing cycle, and in spite of the mold release used on the fixtures, the forming tools were very difficult to remove after the specimen was cured. Figures 2-2 and 2-3 show the insertion of the forming tools and application of adhesive during this first fabrication.

As a result of the problems with the wooden tooling, new fixtures and forming tools were fabricated from metal, and used in constructing the balance of the specimens. The process used is detailed below.

a. Mold release tool parts with Epox-Ease.

b. Assemble a preformed sheet on the base of the tool.

c. Coat node areas with adhesive.

d. Position a second sheet on the first, matching node areas.

e. Press nodes together with a roller or bar.

f. Insert forming pieces.

g. Coat node areas, position sheets, and insert tool parts until the desired stack height has been reached.

h. Place tool assembly and stacked pieces in oven under pressure and cure.

Figures 2-4a through 2-4e show the progressive assembly of the first specimen using the metal tooling. Figure 2-4f shows the completed specimen after removal from the oven.

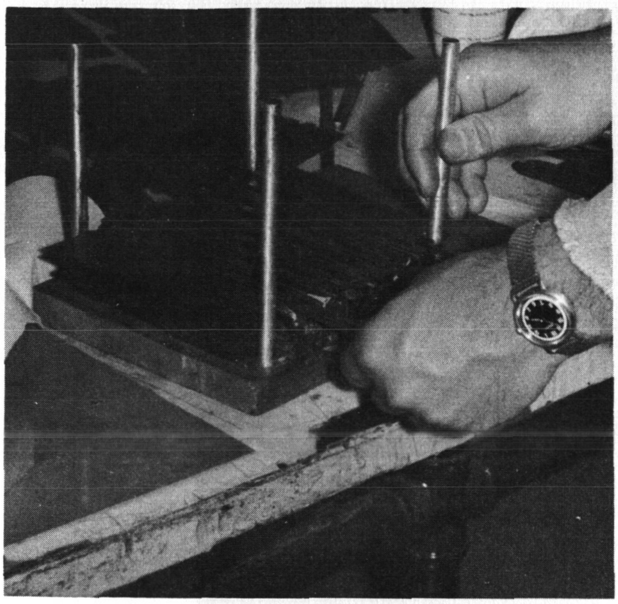


Figure 2-2. Insertion of Forming Tools

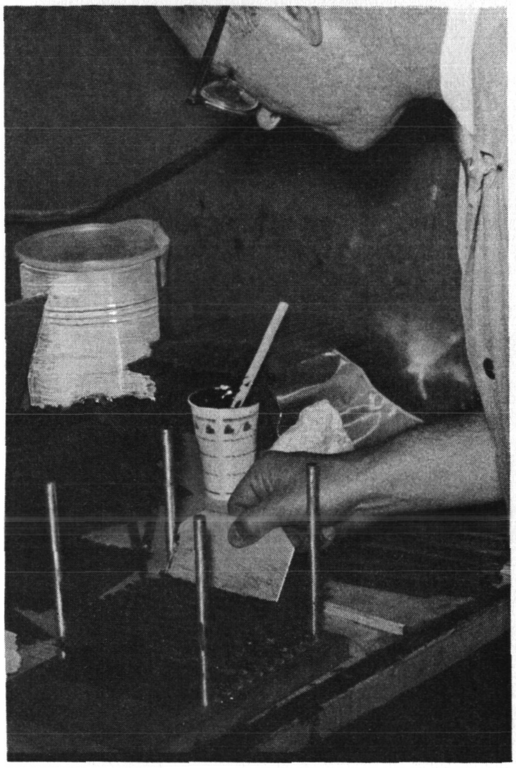
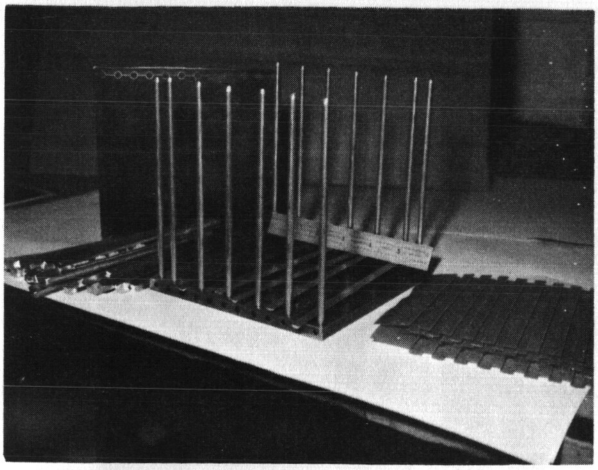


Figure 2-3. Application of Adhesive

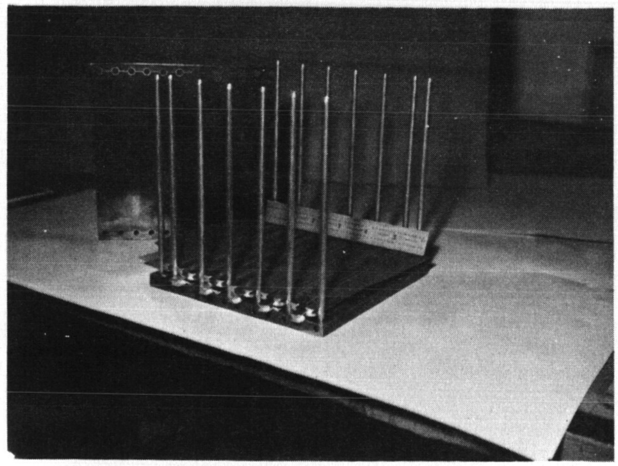
## 2.3 DOVETAIL SPECIMENS EXPANDED 100 PERCENT

The 100 percent expanded dovetail configuration specimens will be fabricated in a manner identical to the 50 percent expanded specimens with the exception of forming of the sheets. Sheets for this configuration will be formed on a set of corrugating dies using the equipment normally used for fabricating standard hexagonal core material by the corrugated process. This equipment consists of two corrugated plates which have the proper cell configuration formed into them and a roller through which the corrugated dies are moved. As the two dies, with the cloth sheet between them, are fed into the roller, the corrugations are formed one at a time. The formation of one at a time prevents any damage to the cloth sheet by eliminating stretching problems.

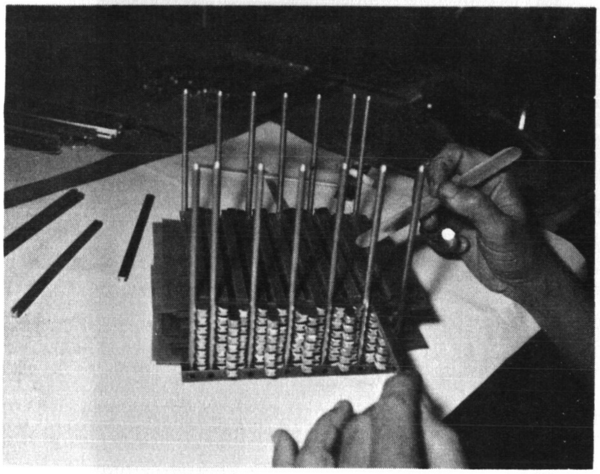
Fabrication of the 100 percent expanded specimens is scheduled to start at the completion of the 50 percent expanded specimens.



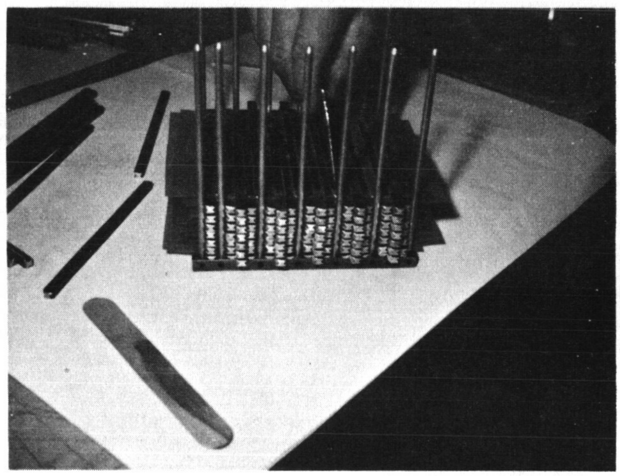
(a)



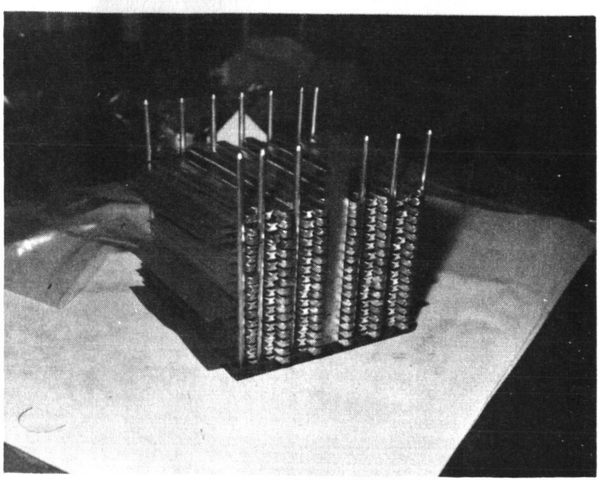
(b)



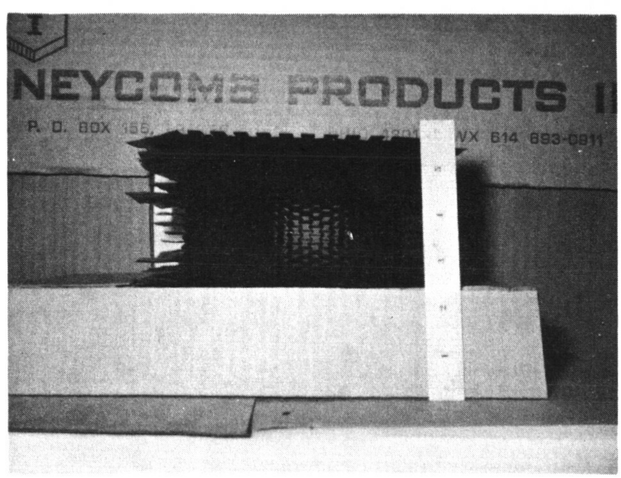
(c)



(d)



(e)




(f)

Figure 2-4. Progressive Assembly of Specimen

## 2.4 CURVED SPECIMENS

Pending completion of successful fabrication of a flat dovetail specimen and testing of this specimen, no work has been performed on the curved specimens. In the process of assembling flat specimens, certain potential problem areas in fabricating larger size specimens were evident. Extremely good tooling will be required for large size specimens since tolerance buildup causes the layup to become mushy or soft as the thickness of layup approaches 3 to 4 inches. This means that the tooling required for one-or two-foot wide specimens will have to include a provision for interim compression of the layup at 3-to 4-inch intervals. In addition to this problem it was noted that the time required for assembling the 3-by 4-by 4-inch specimen was approximately three hours. On this basis, it is apparent that to assemble a large piece in the allowable time, of approximately six hours, as dictated by the node bond resin life, the fixture must include improvements to accelerate the process. In addition to this, more than one person must assist in the assembly. One possible solution to this problem is to have groups of people assembling 3-inch high specimens which could then be stacked together to obtain the required dimension A tradeoff study will be performed in which cost of tooling versus size of specimens that can be fabricated will be investigated. The object of the study is to design fixtures and establish assembly procedures that will permit fabrication of specimens of reasonable size necessary for the curving tests while keeping the tooling cost to a minimum. Where possible, assembly labor will be substituted for tooling in order to reduce the assembly time.

## SECTION 3

## TESTING

### 3.1 HIGH VELOCITY TESTS

Two high velocity impact tests were performed on a nominal 14 pcf, thinned dip, improved bond specimen. The impact velocity was approximately 500 fps. To insure against an explosive type damage of the specimen, which could be caused by air trapped in the specimen during impact, the specimens were sealed in an airtight bag and a vacuum pump was connected to the sealing bag up to and including the time of testing. To protect the bag at the edges of the specimen, putty was placed along these edges. No problems occurred using this type of sealing configuration. A photograph of one of the specimens prior to testing is shown in Figure 3-1.

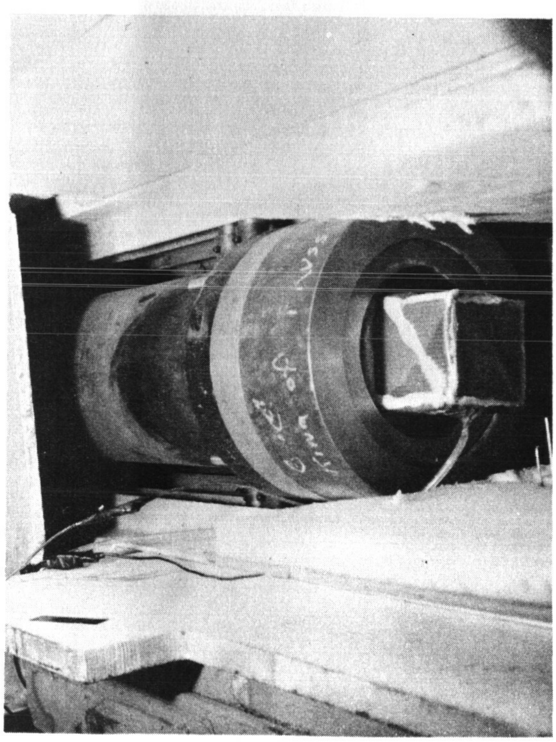


Figure 3-1. Specimen Prior to Testing

Unfortunately, in both tests, the recording instruments malfunctioned and no quantitative data were obtained. However, observation of the specimen after impact indicated that the specimens had crushed in an orderly manner for the entire length of the specimen. This conclusion is based on the fact that only a powdered residue could be found within the test chamber at termination of the tests. Had a specimen split apart or otherwise failed, pieces of cloth, which had not been crushed lengthwise, would have been present.

Further tests of this type of specimen will be performed and reported on in the next reporting period.

## 3.2 STATIC TESTING

### 3.2.1 STERILIZED AND UNSTERILIZED SPECIMENS

As described in the Program Plan, under Task C-1, three static crushing tests were performed at room temperature, on 14 pcf, thinned dip, improved bond specimens which had been exposed to three cycles of sterilization. A cycle consisted of exposure of the specimens to $300^{o}F$ in a nitrogen atmosphere for a period of 36 hours. In addition to these tests, three tests were performed on unsterilized specimens which were cut from the same log of material as the sterilized specimens, in accord with Task B-5 of the Program Plan.

Results of these tests (shown in Table 3-1) indicate that there is no significant effect of sterilization cycle on the energy absorbing properties of the material.

Table 3-1. Test Results

| Description | Test | Principal Steady State Stress (psi) | Density (pcf) | Stroke Efficiency (percent) | Stress to Density Ratio ($10^6$ in.) | Gross Specific Energy ($10^3$ ft-lb/lb) | Specific Energy x Stroke Efficiency ($10^3$ ft-lb/lb) |
|---|---|---|---|---|---|---|---|
| 14 pcf thinned dip improved bond (Sterilized) | C-1-a | 2500 | 13.1 | 73 | 0.330 | 27.6 | 20.2 |
| | C-1-b | 2420 | 12.7 | 71 | 0.330 | 27.6 | 19.6 |
| | C-1-c | 2250 | 12.8 | 72 | 0.304 | 25.4 | 18.3 |
| 14 pcf thinned dip improved bond (Not sterilized) | B-5-a | 2360 | 13.6 | 72 | 0.300 | 25.0 | 18.0 |
| | B-5-b | 2250 | 13.3 | 73 | 0.292 | 24.4 | 17.8 |
| | B-5-c | 2270 | 13.5 | 72 | 0.290 | 24.2 | 17.4 |

## SECTION 4

## ACTUAL VS PLANNED MAN-HOUR UTILIZATION

Figure 4-1 is a graph of actual versus planned man-hour utilization for the period of the contract through July 17, 1966.

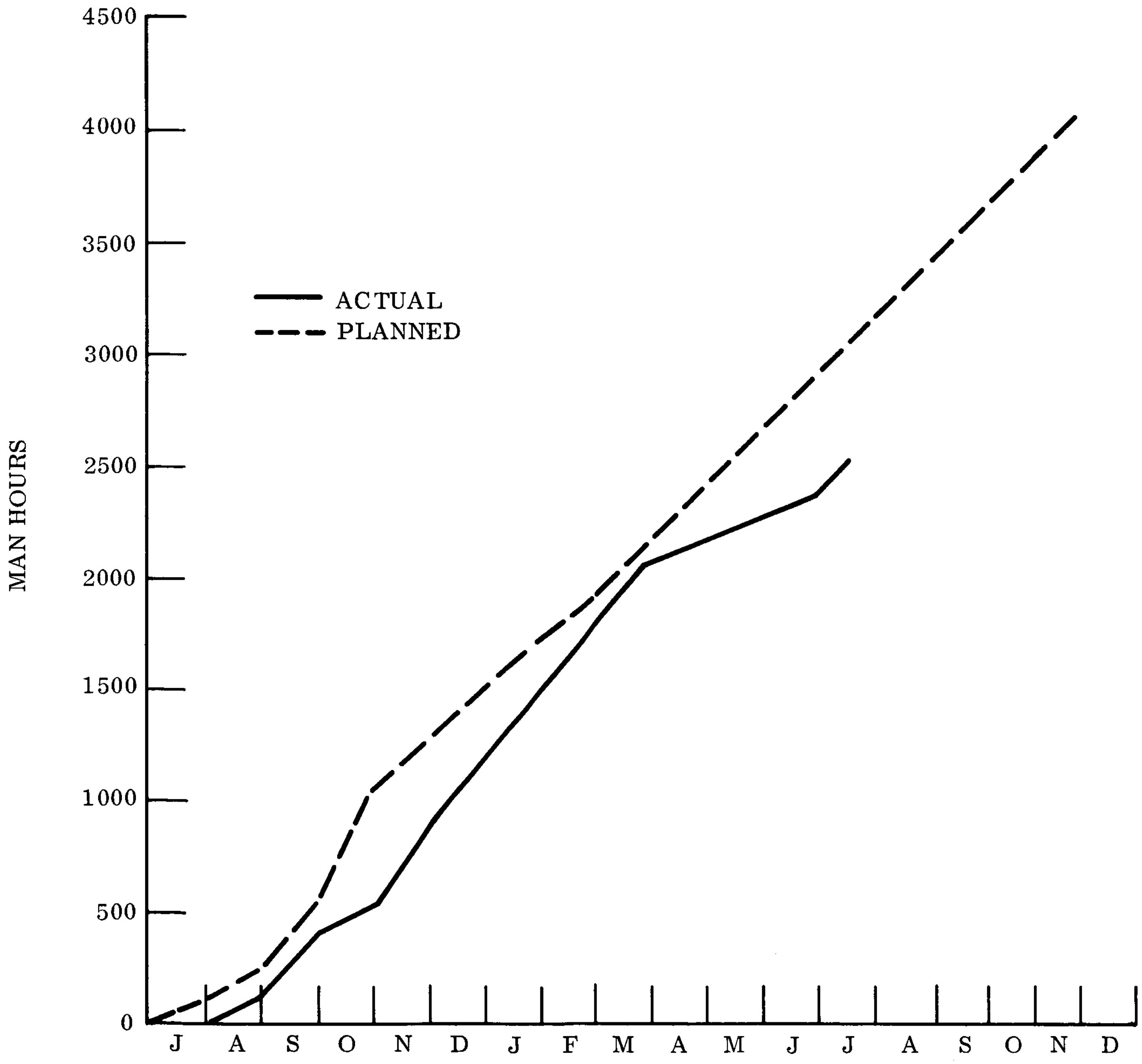



Figure 4-1. Actual vs Planned Man-Hour Utilization

# SECTION 5

# ANTICIPATED PROBLEMS

There is an anticipated problem in the fabrication of curved specimens using the dovetail design. This problem is now one of scope of work, rather than technical. As discussed in Section 2, there are severe limitations in fabricating procedures required for manufacturing a large size dovetail specimen. To reiterate, these limitations require that the specimen be fabricated in a relatively short time. To acquire this short manufacturing cycle, and still produce a specimen of a size which is useful in evaluating the curvability of the material may require the use of elaborate tooling that is more complex than the tooling originally estimated as being required at the beginning of this program. Furthermore, due to problems encountered in fabricating the flat dovetail specimens, and additional time which may be required for obtaining necessary tooling for the large curved specimens, it is becoming increasingly difficult to schedule the required work in the presently alloted time.

Consideration of the problems noted above suggests that the program goals and limitations be reviewed with the customer prior to initiation of tooling procurement and curved specimen fabrication.

## SECTION 6

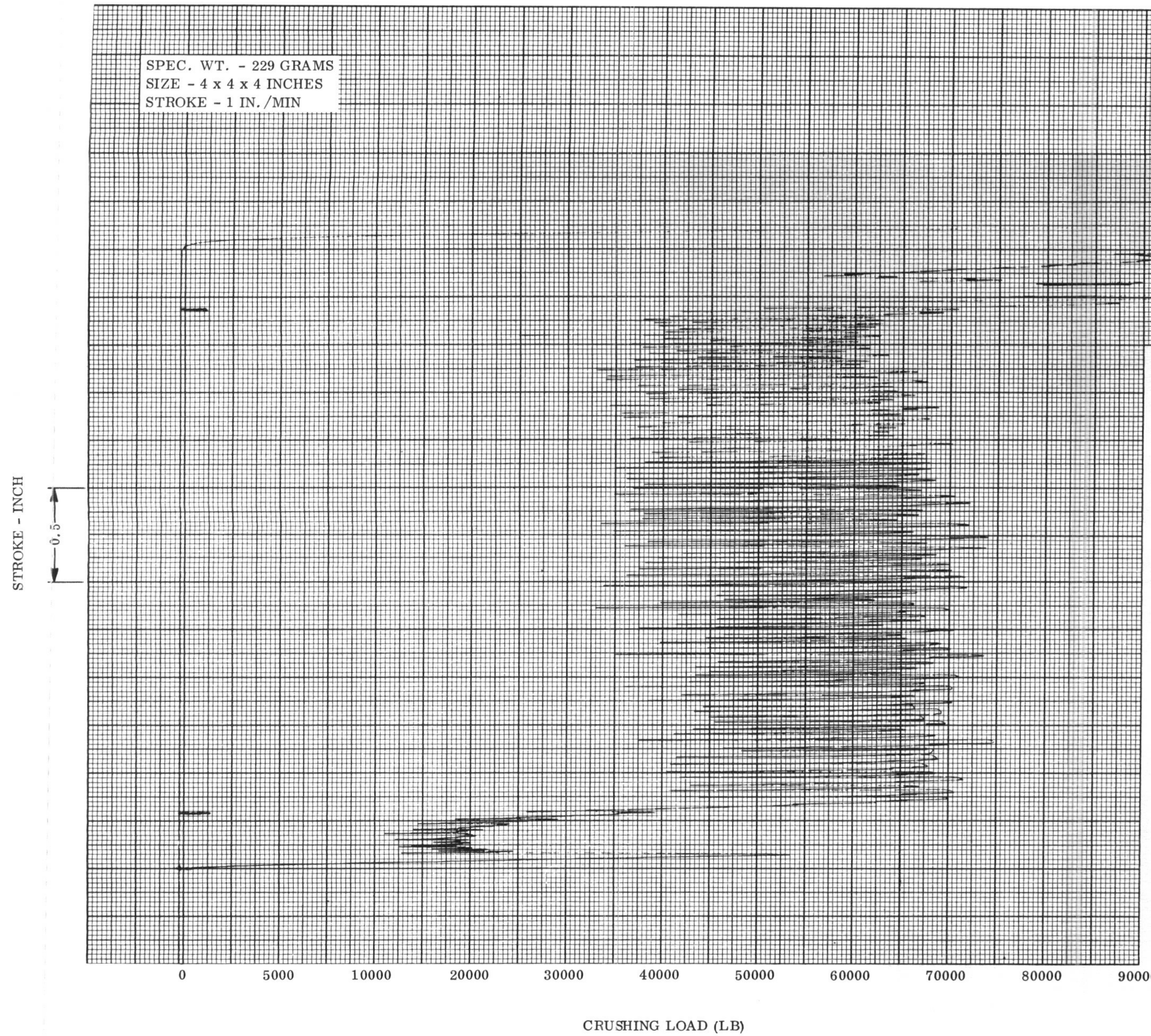
## WORKED PLANNED FOR NEXT QUARTER

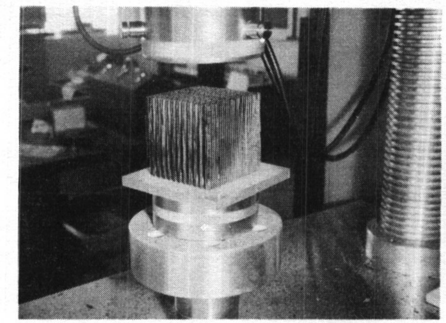
The following work will be performed during the next quarter:

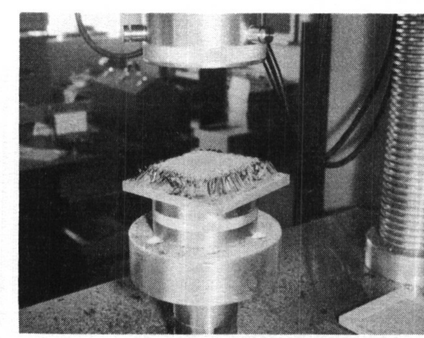
- Fabrication and testing of flat dovetail specimens will be completed.
- Curved specimen configurations will be established, manufactured, and tested.
- Testing of the specimens for Task C-1, the temperature test specimens, will be completed.
- Dynamic testing of the specimens for Task B-5, the thinned dip, improved bond specimens, will be completed.
- Preparation of the final report will be initiated.

# APPENDIX

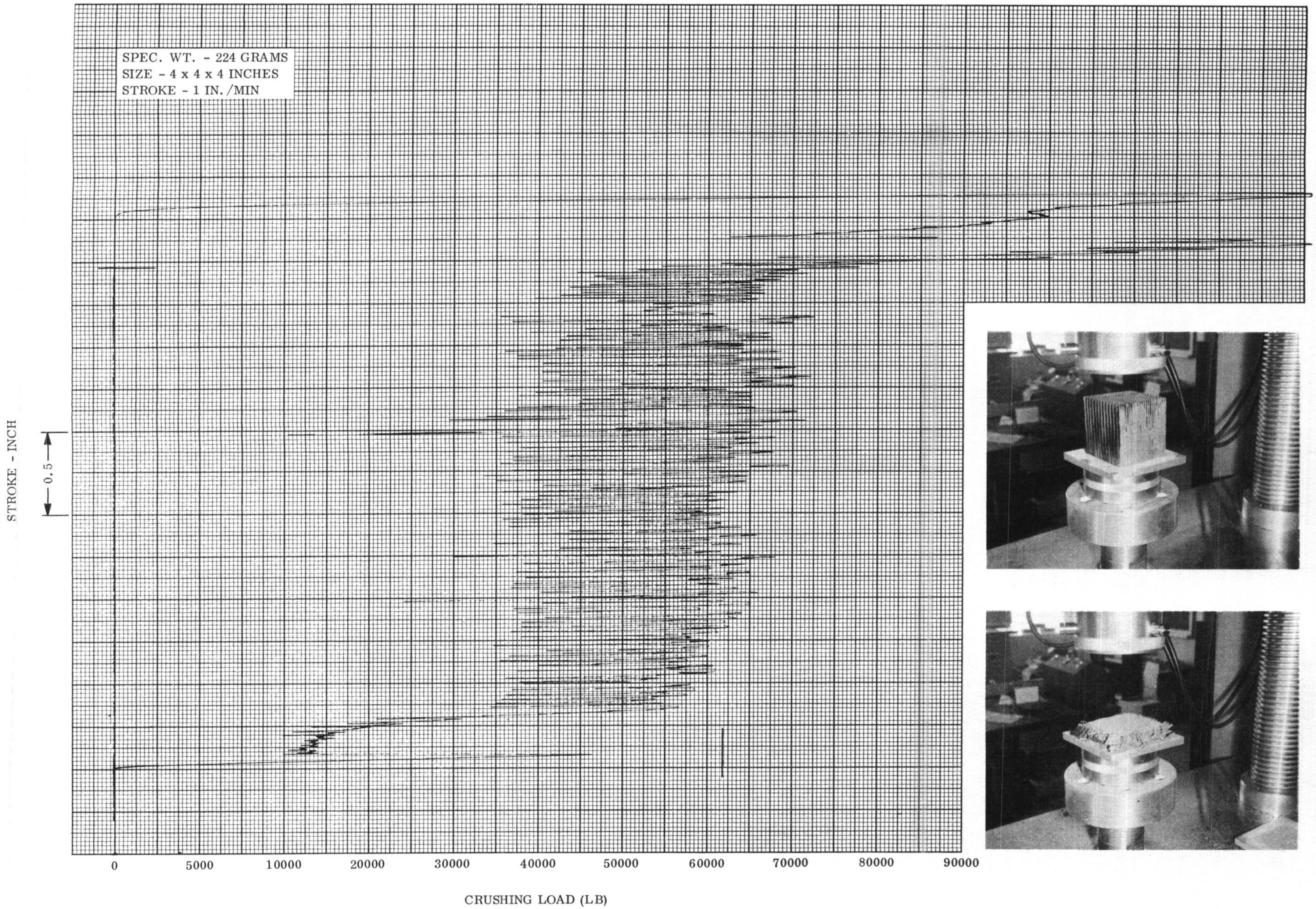
## LOAD DEFLECTION GRAPHS



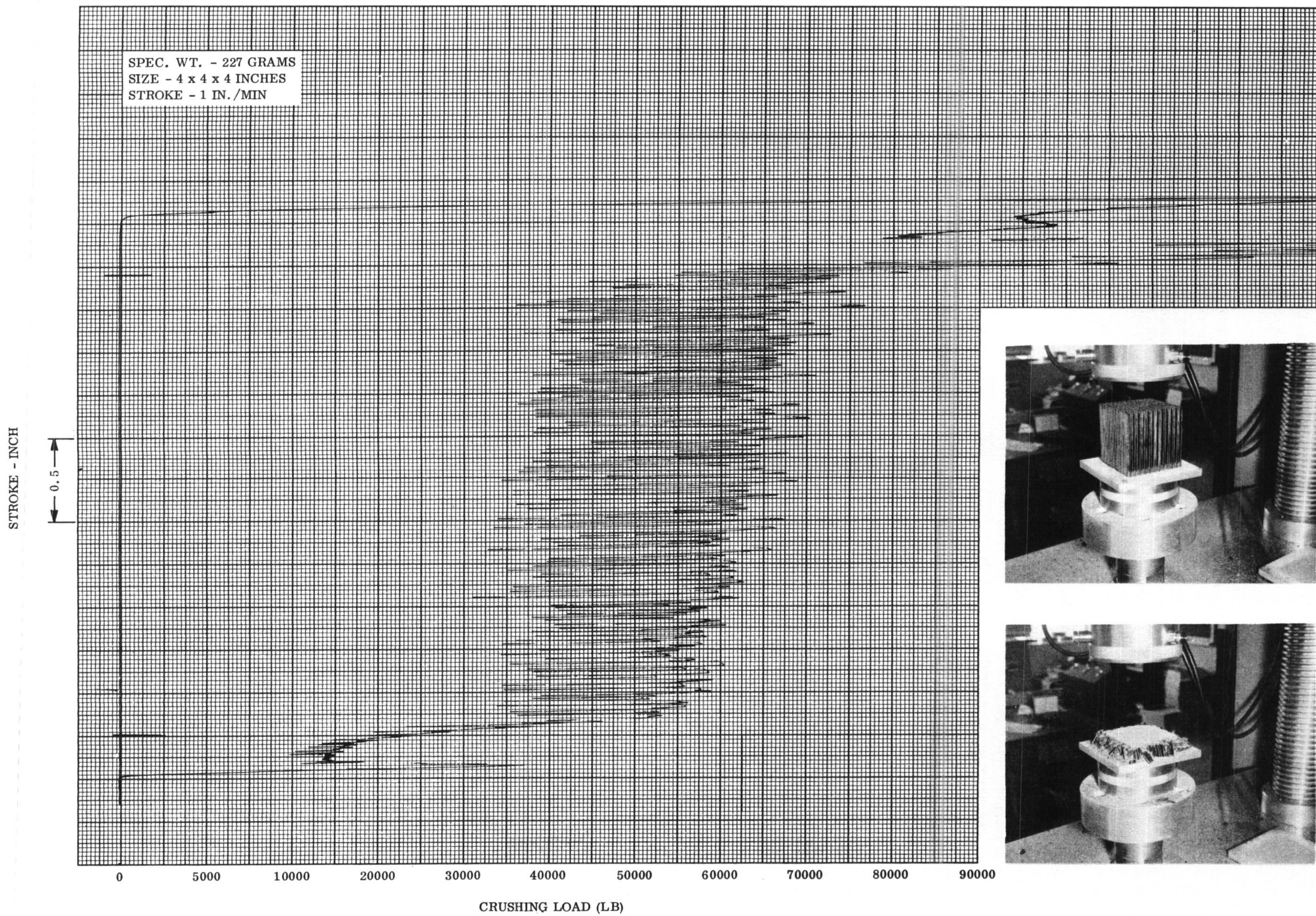





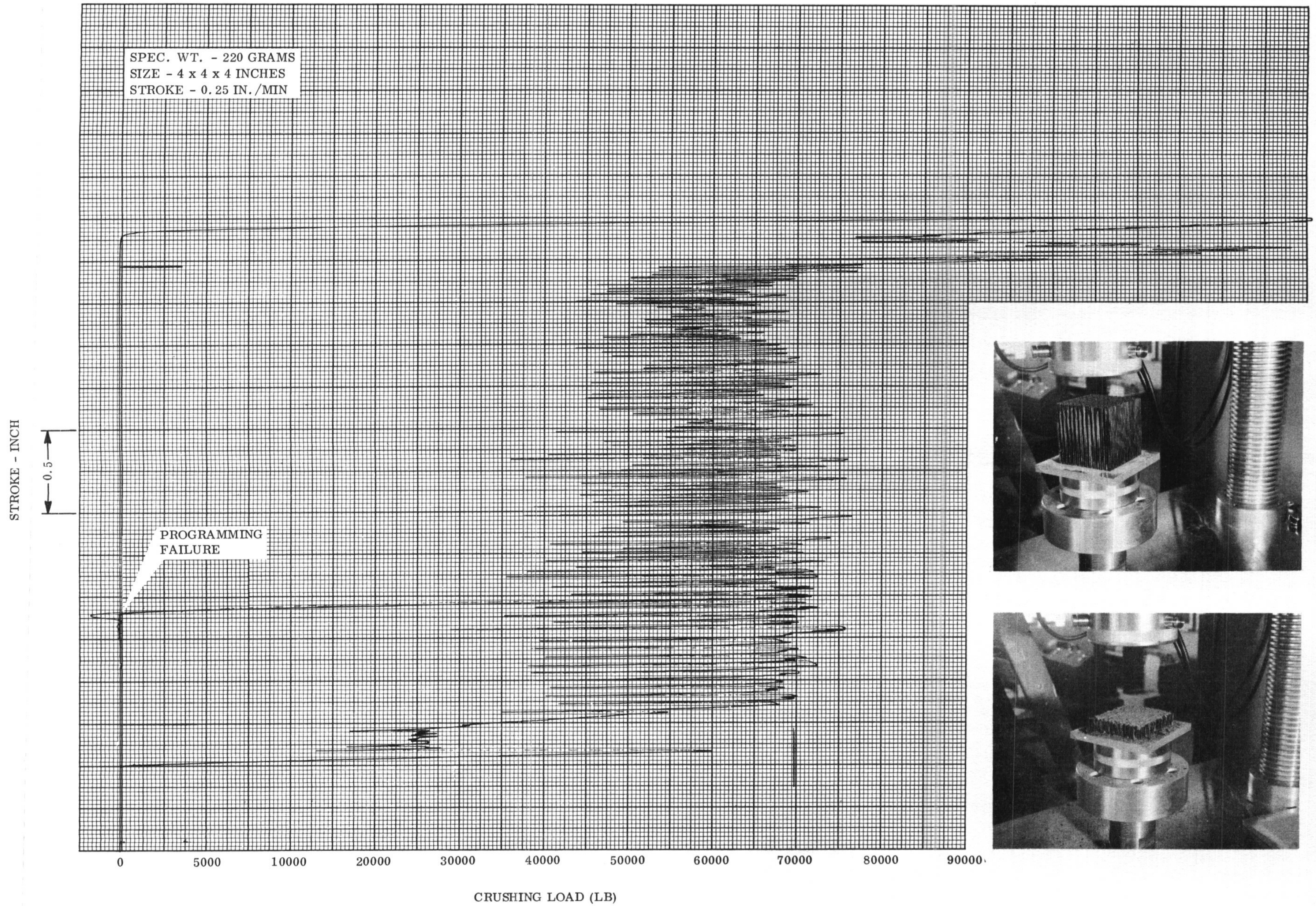
Test B-5-a. 14 PCF-Thinned Dip - Improved Bond (Not Sterilized)



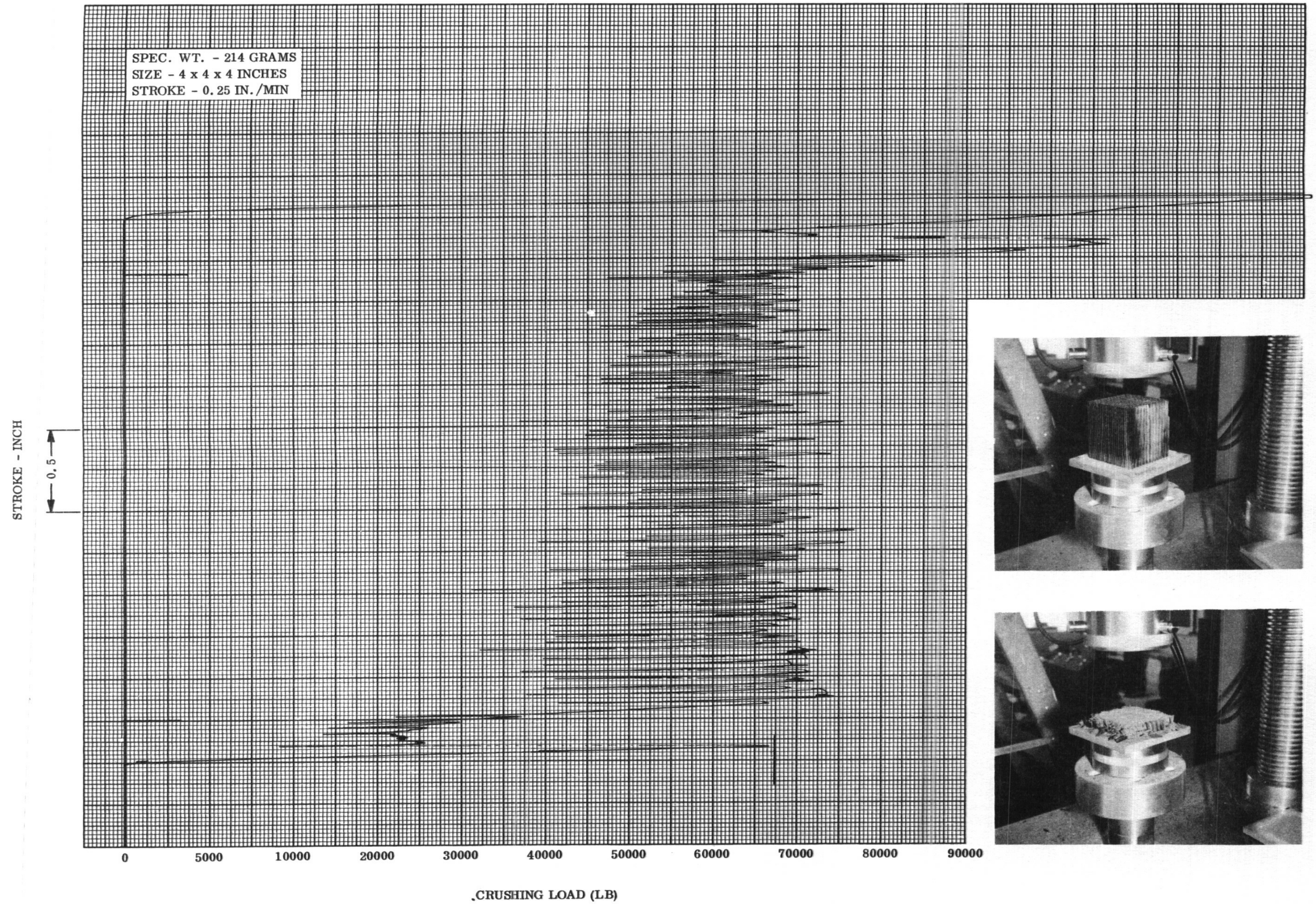

Test B-5-b. 14 PCF - Thinned Dip - Improved Bond (Not Sterilized)



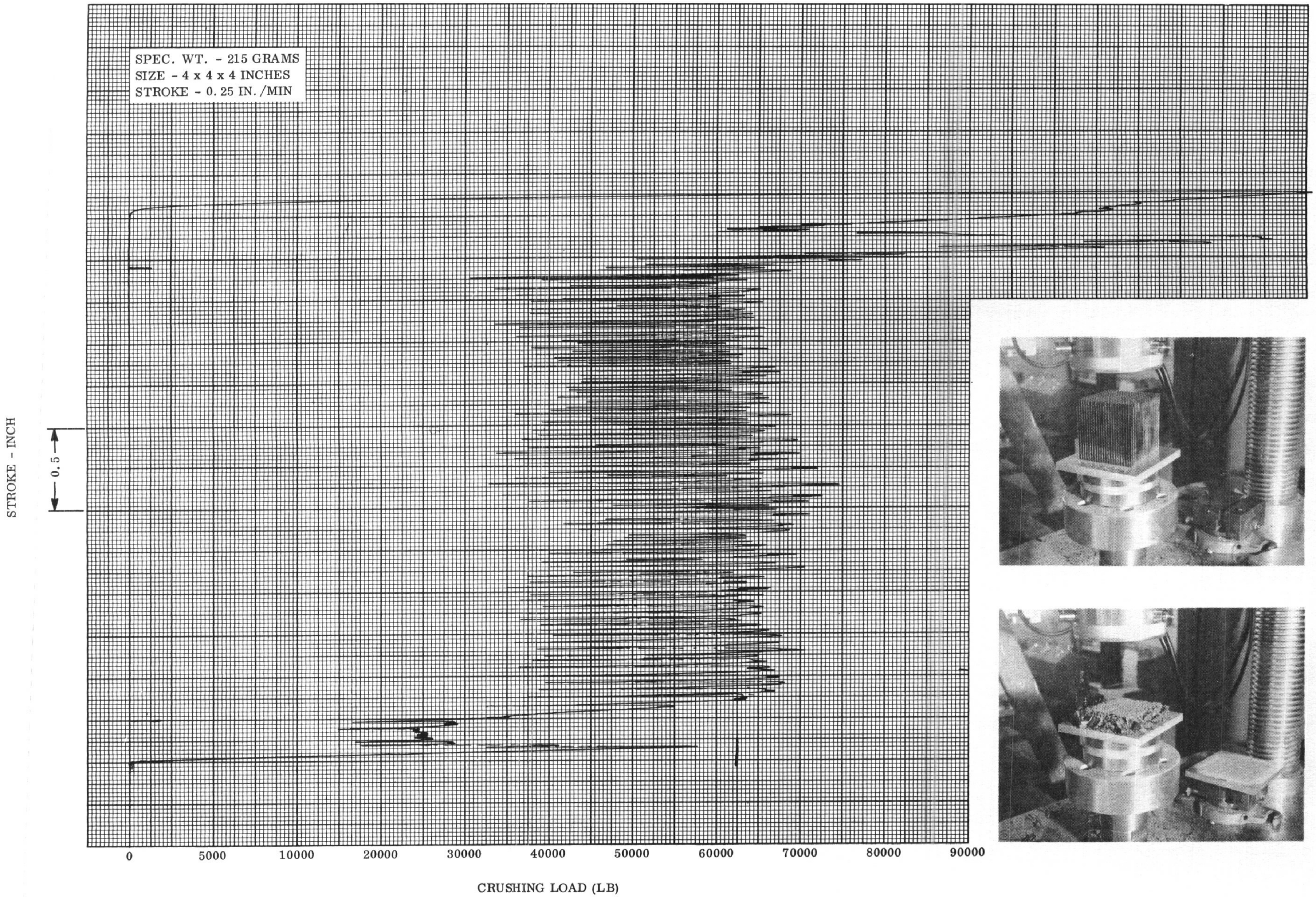

Test B-5-c. 14 PCF - Thinned Dip - Improved Bond (Not Sterilized)




Test C-1-a. 14 PCF - Thinned Dip - Improved Bond (Sterilized)




Test C-1-b. 14 PCF - Thinned Dip - Improved Bond (Sterilized)




Test C-1-c. 14 PCF - Thinned Dip - Improved Bond (Sterilized)